SENSORY BEHAVIOR OF NAVAL PERSONNEL:
MONAURAL/BINAURAL MINIMUM AUDIBLE ANGLE OF AUDITORY RESPONSE

by

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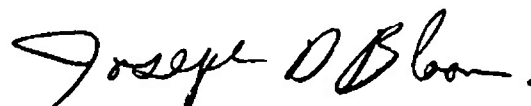NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 607

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9010D.08

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SUMMARY PAGE

THE PROBLEM

To make available information about the ear's performance on various psychoacoustic parameters which is lacking for Navy personnel. This study investigated and reviewed the present status of one such parameter, namely, the ability of one ear to localize an acoustic signal and to relate the findings to a review of facts and theories of sound localization in man.

FINDINGS

Minimum audible angles for monaural localization were determined, monaural/binaural comparisons were quantified, and sound localization theories were reviewed.

APPLICATION

Information in this report is fundamental to specifying man's sensory requirements for optimal orientation in three dimensions. Recommendations on the basis of this study are made to specific questions from the Fleet to insure the most efficient use of the auditory modality in varied operations involving Navy personnel.

ABSTRACT

This paper considers what one ear contributes to man's perception of his auditory world and evaluates the monaural/binaural role in spatial orientation. Minimum audible angles were determined for monaural listening to moving sounds, and results were compared to similarly obtained binaural data. Much usable directionality existed for the monaural mode even at poor azimuths, and for both modes of listening the accuracy of response depended upon type of acoustical signal used. These findings are related to a review of facts and theories of sound localization by man. Recommendations based on the results and conclusions of this study can be made to the Fleet to ensure the most efficient use of the auditory modality in a variety of Naval operations.

does, in fact, use to support exclusively monaural localization. Nothing like a final set of answers to these questions

papers, offered here for the interested reader. Those interested only in re-

Jongkees and van der Veer[21] constructed a hollow artificial head of plaster, filled with cotton wool and having a very thin layer of cotton wool outside the plaster. This head was fitted with a plaster cast of a human auricle, and a microphone at the position of the eardrum. The meatus although presumably of typical dimensions was unspecified, nor was the coupling of the meatus to the microphone mentioned. Polar plots were recorded from the microphone at 0.5, 1, 5, and 10 kHz, when the head with and without the pinna was rotated in the three planes of space. Especially for the high frequencies (above 5 kHz) the information on azimuth available at the microphone lost a good deal of detail without the pinna, especially in the azimuth region near the ear axis. We would point out that in most of the several other artificial head studies, effects of the whole head and of the pinna are hopelessly confounded.

Cancura[22] attributes to the auricle the fact that the audiogram for very high tones can be changed, if the head

between judged vs actual source position for (a), (b), and (c), was .85, .76, and .67 respectively. However, allowing head movements "washed out" these differences.

Batteau[24,25,26], suggested that the rugate nature of the organ, its tragi, antitragi, helices and antihelices may introduce time delays at the eardrum, in response to a single acoustic transient, and that the auditory nervous system can operate on these delays by a process analogous to autocorrelation, as Cherry has suggested, to provide directionality from such time information alone. He was in fact successful in simulating a human pinna using three path lengths, of 1, 2, and 3 inches terminating at the corners of a small right triangle, and converging to a microphone. With one of these artificial pinna, giving delays of about 80 and 160 microsec for the two longer pathways, "definite" localization was possible. This indicates some directionality from a single pinna. Unfortunately, no quantitative tests were made of how localization with this system

In one experiment, Batteau[24] mounted a rubber replica of the left ear of a person on his right side, facing backward. With the left ear blocked, sounds from the front now seemed to come from the rear; and if the ear were mounted upside down, sounds from above seemed to come from below. Again, nothing of a quantitative nature was reported to give magnitude to this interesting observation.

In another experiment Batteau[24] placed S (N:20) in the center of a circle of eight loudspeakers at ear height in 22.5° steps in a reverberant room. S was asked to point to the speaker activated by speech. For binaural hearing the probable error was ± 3.8° after eliminating front-back confusions; for monaural hearing on the plugged side (S stuck his finger in one ear) the average error was 33°; on the open side 30°. These rough data (level of stimulus not reported; azimuth of activated speaker not reported; effect of ear plug not reported; contribution of plugged ear not calculable) do not corroborate the more careful study of Starch[4] on the effect of a plugged ear, the study by Søhoel, et al[11] who did not find any deterioration until binaural asymmetry reached 20-25 dB, or the study by Condamines[12] who found that monaural localization only deteriorated markedly when the sounds came from the plugged side.

Batteau[24] mounted two artificial pinnae an unspecified distance apart in a presumably reverberant room; a rattle was sounded at any of 16 positions spaced at 20° in a circle of unspecified radius around the array. S could well indicate at which azimuth,

or even elevation, the maracas was shaken, but with bare microphones performance was essentially random. This demonstration is inconclusive for the present purposes, since it confounds the time delay (created by the individual pinnae) with the sound shadow of the pinnae and the binaural interactions of S's two ears.

Flynn and Elliott[27] showed that removal of the pinna in cat reduced acuity by 10 dB or more at 0.5 kHz and higher. Evidently the cat pinna serves as a funneling device as its first function in binaural hearing.

Mouzon[28] and Mathes[29] offer anecdotal evidence that complex sounds to one ear alone have different "qualities" in different azimuths. Of course this follows from the differential frequency filtering of the head and pinnae, and is hardly worthy of special remark.

Perrott and Elfner[30] performed a crucial experiment: when two sound sources in the horizontal plane were first equated for loudness, monaural localization (with no head movement permitted) fell off to chance. Thus, the characteristics of the anatomy of the head and pinna were the substrate; in all probability, the intensity differences rather than the time differences provided for monaural localization.

Experimental confirmation of the ancient suggestion that the pinna largely provides for verticality judgments has been supplied by Roffler and Butler[31] and Butler[32].

(3) Head Movements. Many authors have correctly noted that diotic

conditions in an immobile head can furnish a multitude of ambiguous directionality cues (for a full treatment see Matsumoto[33] and any good recent text on experimental psychology), which can only be resolved by small head movements. Such movements are of course always present synchronized with the pulse of the order of five sec arc, and are present at random of the order of 3° even with the head supported (Konig and Sussman[34]). (On the other hand, Kietz[35] found good directionality for clicks which were much too brief to allow for head movements.)

Young,[36] in his classic pseudophone experiment, first emphasized the role head movements play in localization, for either the monaural or binaural mode. He implied that localization judgments are based upon a totality of interaural differences, effects to which one ear alone is susceptible, and to a host of visual, labyrinthine, and kinesthetic cues, all usually congruent in meaning. Young[37] modified his pseudophone so that head movements did not change the acoustics at the trumpet pickup, and found that three-dimensional discrimination was impossible. An explanation of his results is possible in monaural terms by noting that the numerous ambiguities render good localization impossible when the pinnae and head, and movements thereof, are prevented from modifying waveform and absolute intensity at a single ear.

Wallach[38] noted the importance of head-turning for performance especially of front-back discrimination, and Christian and Röser[39] noted the importance of head-turning for perform-

ance of monaural hypacusics who had audiometric asymmetries of 30+ dB.

Jongkees and van der Veer[21] repeated on 20 Ss an experiment of Klensch[40] using tubes about 2 ft long sealed into the meati and ending in small funnels, the polar patterns of which were unspecified but presumably symmetrical. Each tube, and S's head, could be moved together or all three independently. Unfortunately, an echo-free chamber was not available. Their results were:

(a) With both head and funnels immobile, no Ss externalized the sound; it all seemed within the head.

(b) With head fixed, tube movements caused the sound image within the head to move left and right.

(c) With head oscillated and the funnels moving in congruent fashion, the sound was externalized to its real position. Crossing the tubes led to a condition where the sound seemed to lie in the rear of S, as logically it should. A head movement of only 10°, combined with appropriate funnel movement, was sufficient to induce good externalization and directionality, however.

(d) With head oscillated and the funnels moving in noncongruent fashion (i.e., when head turned left, so that the right ear was nearer the loudspeaker, the funnel was pulled away from the loudspeaker) the sound was externalized to the rear.

(e) With the whole body oscillated on a revolving chair (thus giving

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rise to minimal neck reflexes), seven of the 20 Ss lost directionality. Evidently, congruent kinesthetic cues have a real role in directionality. However, in a test of directionality with ten Ss, the head loosely fixed or completely immobilized with a dental mouthpiece and two other clamps, head movements did not contribute to directional efficiency in the horizontal plane.

All of the experiments to date on monaural localization have used stationery sound sources, and usually very coarse steps in degrees from one loudspeaker to the next. For example, in one of the better experiments (Fisher and Freedman[23]) the sources were 22.5° apart; yet the minimum audible angle (m.a.a.) which the binaural head can achieve is of the order of 1-2°; any superiority of the binaural condition thus might be quite obscured by the coarseness of the measure.

It occurred to us that a moving sound source, which should yield a continuous set of changing loudness/phase/timing cues available to the single ear as a loudspeaker swept through some azimuth, if combined with an m.a.a. technique providing fine measures of performance, might furnish a more complete quantification of the monaural/binaural comparison than is now available. Therefore, the following experiment was conducted.

III. METHOD

General. S sat in front of a track upon which a loudspeaker rode on a little cart, and judged whether during a tone burst the loudspeaker moved left or right.

Subjects. Three experienced male staff members with essentially normal hearing served. All Ss judged under all stimulus conditions.

Workspace. The experimenter, S, and two loudspeakers were in an anechoic cube of 33,000 cu ft. All other apparatus was in an adjoining control space.

Apparatus and Procedure. A straight aluminum I-beam was mounted diagonally across a corner of the room, 3 ft above the grille floor, and S was seated 10 ft from and facing the center of the beam. A Janssen 15-inch triaxial loudspeaker in its commercial cabinet was placed on a cart which could be pulled at a constant speed of 6.5 inches/sec by a system consisting of a reversible DC motor, wire thread, and pulleys. The movement of the cart over the midline (0° azimuth) triggered a Grason-Stadler timer-switch combination which shaped and gated the output of either a General Radio oscillator or noise generator. The duration of the signal in msec governed the degree of azimuth swept through by the sounding source.

The sounds of the DC motor, pulleys, wheels, etc., were almost inaudible to S and were in any case noninformative. Nevertheless these unwanted noises were completely masked by a low level white noise originating from a second loudspeaker directly behind S. During any trial the experimenter positioned himself well out of any direct sound path.

In the binaural mode, S simply sat blindfolded facing the 0° azimuth. Steps

taken to create the monaural mode with pure tones were:

(a) Background noise on second speaker was set to mask apparatus noises;

(b) Open-ear binaural free-field threshold was obtained for the stimulus of the session; the stimulus pulsing 0.5-sec on, 0.5-sec off, the background noise on throughout;

(c) Main loudspeaker level was increased by 18 dB and "NODS" (wax-impregnated commercial earplugs) inserted into both ears.

Thus far we were pretty well assured that the NODS would prevent the S from hearing the output of the main speaker, but to make doubly sure,

(d) A circumaural muff was applied over the ear to be inactivated, and, furthermore, within that muff an earphone driver allowed for

(e) a masking white noise set 5 dB over the level at which it may have been found necessary to prevent hearing the 0.5-sec pulses of the main loudspeaker.

Thus the S's inactive ear was shielded from the sound source by an earplug, a circumaural muff, and, if necessary, a special low-level masking noise. Of course all these were removed from the test ear for the monaural condition.

The binaural mode stimulus level was always 18 dB over the threshold as in (b) above.

A series of runs, each consisting of five trials to the right and five to the left in random order, at a certain degree of arc (.25 - 12°) were given by the Method of Serial Exploration and the 75%-correct point found by graphic interpolation. This point was taken as the m.a.a., determined for 0.8, 1.6, 3.2, and 6.4 kc/s, and for white noise, at 0 and at 60° azimuth.

IV. RESULTS AND DISCUSSION

The m.a.a. are given in Table I. For one of the 30 threshold measures determined at 0° azimuth and for ten of 30 at 60°, the values were too large for our equipment to measure before the discrepancy between the arc and the chord of loudspeaker movement might have intruded, and these values are listed simply as $> 12°$.

Direct comparisons of the monaural/binaural modes are given in Fig. 1 (0° az.) and Fig. 2 (60° az.). One trend is clear for the monaural mode to be inferior at 0° ($<.001$ by a one-tailed Wilcoxon test) though not in the lower frequency range and not for white noise. A second trend is clear for the monaural mode to be inferior at 60° (.001 by the Wilcoxon test) though not at the higher frequencies, nor again for white noise. There is, thus, an interaction between mode and azimuth, Figs. 3-4 replot the data to show that this interaction is largely affected by the monaural mode (note that in the binaural mode the azimuth effect is preponderant only at 6.4 and perhaps 1.6 kHz). However, Wilcoxon's one-tailed tests indicate that the binaural m.a.a. are in fact smaller at each azimuth separately ($<.001$).

Table I. Minimum Audible Angle in Degrees for Moving Target

Stimulus	Subject	0° Azimuth		60° Azimuth	
		Monaural	Binaural	Monaural	Binaural
White Noise	H	1.5	3.0	4.5	6.0
	S	3.5	0.5	1.0	1.5
	M	4.5	0.5	2.5	2.5
0.8 kHz	H	4.0	4.0	12.0	3.0
	S	4.5	4.5	10.5	3.5
	M	2.0	2.0	12.0	7.5
1.6 kHz	H	2.0	3.5	12.0	2.5
	S	9.5	2.0	11.5	6.5
	M	7.0	1.5	9.5	11.5
3.2 kHz	H	4.0	3.5	7.5	2.0
	S	6.5	1.0	3.5	3.5
	M	10.0	4.0	12.0	12.0
6.4 kHz	H	12.0	1.5	12.0	12.0
	S	5.5	5.0	12.0	6.5
	M	8.0	1.5	12.0	12.0
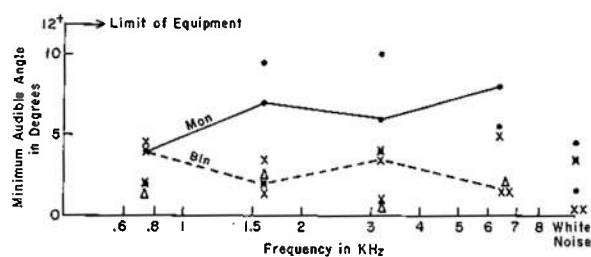
Fig. 1. Comparison of Monaural/
Binaural Minimum
Audible Angles at 0°
Azimuth.
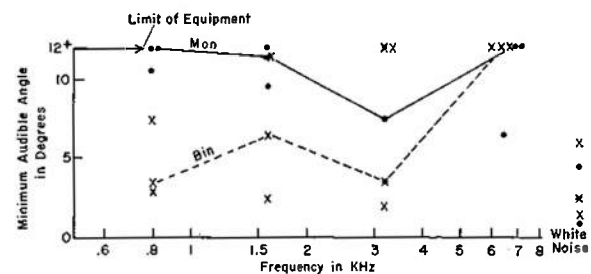
Fig. 2. Comparison of Monaural/
Binaural Minimum
Audible Angles at 60°
Azimuth.

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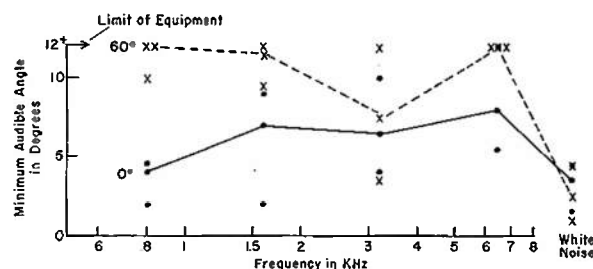
Fig. 3. Comparison of Azimuth
Effect in the Monaural
Mode.

Fig. 4. Comparison of Azimuth
Effect in the Binaural
Mode.

A first conclusion we may draw from these data is that when the experimental conditions are made sensitive enough, the advantage of a second ear becomes obvious. Fig. 1 shows that if an experimenter is satisfied with a 10° blurring inherent in his apparatus, differences in the monaural/binaural responses would be entirely obscured; yet it will be recalled that the usual experiment positioned loudspeakers often 45° and seldom less than 22.5° apart. Fig. 2 shows that at 60° azimuth the monaural m.a.a. often exceeds 10°, but never for all Ss at any frequency, and indeed for white noise the monaural/binaural difference is negligible even at the 60° azimuth. It thus seems possible to explain the discrepancy between clear effect in these data, vs the general lack of effect mentioned in the literature review above, largely on the basis of sensitivity of measurement.

One makes, however, more of the similarities than of the differences in monaural/binaural m.a.a., since even when the monaural mode is shown to be inferior, the m.a.a. has deteriorated only by a maximum factor of

two -- in other words, monaural localization has not deteriorated to unusability at any frequency or at any azimuth. Fig. 3 shows the worst case: only at 6.4 kHz at 60° are all Ss' m.a.a. worse than 12°, and the raw data indicate even there that two Ss reached 70%-correct at that setting, and another reached 65%. Evidently deterioration is far from complete. Fig. 1 shows the best case: at 0° azimuth the worst monaural m.a.a. was only 7°.

With the general effect established of sometimes deteriorated but still quite usable monaural localization, one is led to look for the kinds of cue which a one-eared S has available for decision. Several clues are provided in these data, concerned both with frequency content and azimuth.

The data for white noise are instructive, in that both high and low frequencies are represented. We see not only that the monaural/binaural difference vanishes at both 0° and 60°, but also that m.a.a. for white noise is as good at 60° as at 0°. Evidently the human seizes upon any clue

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available in order to make his decisions, and at some frequency even the worst case (monaural at 60°) finds some differential cue.

We may reason that there can be no question of centrally - or even peripherally-based deterioration of time or intensity discriminations peculiar to some frequency or azimuth; and the only question can be, what are the acoustic differences in (1) intensity, (2) spectral analysis, or (3) temporal patterning resulting from multiple-delay reflections off the pinna, on the basis of which S can distinguish between loci of sound source.

One hint from our data concerns the marked deterioration of monaural m.a.a. at 60°, but not at 0°. In the median sagittal plane the frequency of 0.8 kHz throws some sound shadow, and this (coupled with a sensitivity to change in phase as the stimulus is moved from the midline either toward or away from the open ear) gives S all the clues to directionality he needs. At the higher frequencies where phase is inutile, the head shadow assumes a role a bit less efficient, but still useful.

At 60° where the sound path is looking more directly into the ear, the differential sound shadow for adjacent points in space can be shown to be reduced, and in fact the m.a.a. is deteriorated at 60° for all pure tones.

The binaural m.a.a. for a moving target as used here can be directly compared to data on the binaural m.a.a. for a stationery source (Harris[41]) for the identical Ss (See Table II). The means from Table II

Table II. Binaural M.A.A. in Degrees at 0° Azimuth (Using an Acoustic Zero) (Part of Table 16 from Harris[41])

Subject	Frequency in kiloHertz			
	0.8	1.6	3.2	6.4
S	1.6	3.2	.6	1.6
H	1.6	1.7	.9	1.3
M	1.2	2.5	.7	2.4
Mn:	1.5	2.5	.7	1.8

are entered in Fig. 1 as triangles, and it can be seen that at 0° azimuth the two types of binaural m.a.a. are always indistinguishable, though it may be that the m.a.a. for the stationery target are superior on the average at 0.8 and 3.2 kHz.

The theory of localizing sound sources using the auditory modality is basic to many tasks being performed by Navy personnel. For example, free-swimming divers must utilize innate sensory capacities to orient themselves in three dimensional underwater space, to navigate, locate and/or avoid obstacles, and localize various sound sources underwater. Some men monitor different communication systems which require localization of specific loudspeakers for recognition. Many other examples become obvious to the human factors engineer who mates man and machine in the performance of particular Navy-oriented tasks.

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A full understanding of man's sensory ability to localize sound must make use of basic theoretical aspects underlying such behavioral performance. The review reported herein supplies information from which recommendations are made to the Fleet to ensure the most efficient use of the auditory modality of Navy personnel with a variety of Naval operations.

V. SUMMARY AND CONCLUSIONS

Three men highly experienced in listening, (1) with both ears open, and (2) with one ear plugged, muffed, and noise-masked, judged whether a sound source (bursts of white noise or tones of 0.8, 1.6, 3.2, or 6.4 kHz) moved left or right of (1) the horizontal midline, or (2) a point 60° off midline. A loudspeaker moved along a track at 6.5 inches/sec at a distance of 10 ft from the subject. Minimum audible angles (m.a.a.) were computed as being that arc of which the direction was correctly detected on 75% of the trials. The binaural m.a.a., of the order of 2° for all stimuli at 0° azimuth, was equally good at 60° azimuth for white noise, but worse by a factor of two or more for pure tones, especially at 6.4 kHz. These m.a.a. are a bit better at some frequencies than the m.a.a. yielded by the same Ss for stationery targets in a previous report. The monaural m.a.a. at both azimuths were as good as the binaural m.a.a. for white noise, and for the lowest tone at 0° azimuth, but were distinctly inferior elsewhere. Both the azimuth and monaural/binaural mode effects reached high formal significance on one-tailed tests. A special

deterioration of the monaural mode at 60° can be explained by a reduction at 60° of the differential sound shadow for sources at adjacent points in space. In toto, however, the data show much usable directionality for even the monaural mode at even the worse azimuth.

This investigation and review of man's ability to localize sounds in space supplies basic information about the ear's performance. Recommendations on the basis of this study can be made to the Fleet to ensure the most efficient use of the auditory modality in a variety of Naval operations.

REFERENCES

1. Mills, A. W. On the minimum audible angle. J. Acoust. Soc. Amer., 1958, 30, 237-246.

2. Pierce, A. H. Studies in Auditory and Visual Space Perception. N.Y.: Longmans, Green, 1901.

3. Seashore, C. E. Localization of sound in the median plane. Univ. Iowa Stud. in Psychol., 1899, 2, 46-54.

4. Starch, D. Perimetry of the localization of sounds. Psychol. Monogr., 1905, No. 28, 1-45; 1908, 9, No. 38, 1-55.

5. Angell, J. R. and Fite, W. The monaural localization of sound. Psychol. Rev., 1901, 8, 225-246. Further observations on the monaural localization of sound. Psychol. Rev., 1901, 8, 449-458.

6. Ferree, C. E. and Collins, R. An experimental demonstration of the binaural ratio as a factor in auditory localization. Amer. J. Psychol., 1911, 22, 250-297.

7. Jongkees, L. B. W., and Groen, J. J. J. Laryngol. Otol., 1946, 61, 494. Cited in Reference 28.

8. Jongkees, L. B. W., and Veer, R. A. van der. Directional hearing capacity in hearing disorders. Acta Oto-Laryngol., 1957, 48, 465-474.

9. Bergman, M. Binaural hearing. Arch. Otolaryngol., 1957, 66, 572-578.

10. Bauer, R. W., Matuzsa, J. L. and Blackmer, R. F. Noise localization after unilateral attenuation. J. Acoust. Soc. Amer., 1966, 40, 441-444.

11. Søhoel, T., Arnesen, G. and Gjavenes, K. Sound localization in free field and interaural threshold differences. Acta Oto-Laryngol. Suppl. 1963, 188, 293-297.

12. Condamines, R. Le reperage directionnel des sons en ecoute mono et biauriculaire. Paper B63, Ve Congres International D'Acoustique, Liege, Belgium, 1965, 7-14 Sept, Pp. 4.

13. Fisher, H. G., and Freedman, S. J. The role of the pinna in auditory localization. J. Audit. Res., 1968, 8, 15-26.

14. Viehweg, R., and Campbell, R. A. Localization difficulty in monaurally impaired listeners. Ann. Otol., Rhinol., Laryngol., 1960, 69, 622-634.

15. Butler, R. A., and Naunton, R. F. Some effects of unilateral auditory masking upon the localization of sound in space. J. Acoust. Soc. Amer., 1962, 34, 1100-1107.

16. Butler, R. A., and Naunton, R. F. The effect of stimulus sensation level on the directional hearing of unilaterally deafened persons. J. Audit. Res., 1967, 7, 15-23.

17. Kitagawa, S., and Shintaku, Y. Direction perception and subjective auditory direction line. Acta Otolaryngol., 1957, 47, 431-443.

18. Sinclair, J. C., and Wruk, K. R. A test apparatus to measure a person's ability to spatially localize a sound source. Proc. Symposium on Biomed. Engnrg., Vol. I, 1966, 197-199. Marquette Univ., Milwaukee, Wisc.

19. Briskey, R. J., and Sundquist, J. H. Procedures and experimental application of localization tests. Proc. Symposium on Biomed. Engnrg., Vol. I, 1966, 295-299. Marquette Univ., Milwaukee, Wisc.

20. Diamant, H. Sound location and its determination in connection with some cases of severely impaired function of vestibular labyrinth, but with normal hearing.

Acta Otolaryngol., 1946, 34,
576-586

21. Jongkees, L. B. W., and Veer,
R. A. van der. On directional
sound localization in unilateral
deafness and its explanation. Acta
Oto-Laryngol., 1958, 49, 119-131.

22. Cancura, W. Über die Bedeutung
der Ohrmuschel fur die Wahrneh-
mung besonders hoher Töne.
Mschr. Ohrenheilk., 1967, 101,
497-502.

23. Fisher, H. G., and Freedman,
S. J. Localization of sound during
simulated unilateral conductive
hearing loss. Acta Oto-Laryngol.,
1968a, 66, 213-220.

24. Batteau, D. W., and Associates.
(On human localization of Sound).
Parts 1-5 of May, 1961; March,
1962, Sept., 1963., Dec., 1963;
and Jan., 1965. Reports prepared
for US Naval Ordinance Test Sta-
tion, China Lake, Calif.

    Part 1: Batteau, D. W. Char-
acteristics of human localization
of sound.

    Part 2: Batteau, D. W., and
Plante, R. L. The mechanism
of human localization of sounds
with applications in remote en-
vironments.

    Part 3: Batteau, D. W. Locali-
zation of sound: a new theory of
human audition.

    Part 4: Batteau, D. W., and
Plante, R. L. Further develop-
ments in sound localization.

    Part 5: Batteau, D. W., Plante,
R. L., Spencer, R. H., and
Lyle, W. E. Localization of
sound: Auditory perception.

25. Batteau, D. W. The role of the
pinna in human localization. Proc.
Roy. Soc., Series B., 1967, 168,
No. 1011, 158-180.

26. Batteau, D. W. Listening with the
naked ear. In: S. J. Freedman
(Ed.) The Neuropsychology of
Spatially Oriented Behavior.
Homewood, Ill.: Dorsey Press,
1968.

27. Flynn, W. E., and Elliott, D. N.
Role of the pinna in hearing.
J. Acoust. Soc. Amer., 1965,
38, 104-105.

28. Mouzon, J. C. Stereophonic hear-
ing with one earphone. J. Acoust.
Soc. Amer., 1955, 27, 381 (Ltr
to Ed.)

29. Mathes, R. C. Monaural direction
finding. J. Acoust. Soc. Amer.,
1955, 27, 792 (Ltr to Ed).

30. Perrot, D., and Elfner, L. F.
Monaural localization. J. Audit.
Res., 1968, 8, 185-193.

31. Roffler, S. K., and Butler, R. A.
Factors that influence the localiza-
tion of sound in the vertical plane.
J. Acoust. Soc. Amer., 1968, 43,
1255-1259.

32. Butler, R. A. Monaural and bin-
aural localization of noise bursts
vertically in the median sagittal
plane. J. Audit. Res., 1969, 9.
(In Press).

33. Matsumoto, M. Researches on
    auditory space. Stud. Yale
    Psychol., Lab. 1897, 5, 1-75.

34. König, G., and Sussman, W. Zum
    Richtungshören in der Median-
    Sagittal-Ebene. Arch. Ohr. u.
    Heilk., 1955, 167, 303-307.

35. Kietz, H. Das Problem des
    Raumlichen Richtungshören.
    Z. Laryngol., Rhinol., Otol.,
    1952, 31, 91-94.

36. Young, P. T. Auditory localization
    with acoustical transposition of the
    ears. J. Exper. Psychol., 1928,
    11, 399-429.

37. Young, P. T. The role of head
    movements in auditory localiza-
    tion. J. Exper. Psychol., 1931,
    14, 95-124.

38. Wallach, H. On sound localization.
    J. Acoust. Soc. Amer., 1939, 10,
    270-274.

39. Christian, W., and Röser, D. Ein
    Beitrag zum Richtungshören.
    Z. Laryngol., 1957, 36, 432-445.

40. Klensch, H. Beitrage zur Frage
    der Lokalization des Schalles im
    Raum. Pflug. Arch. ges.
    Physiol., 1948, 250, 492-500;
    706-713.

41. Harris, J. D. Identifying and
    teaching of auditory cues for
    traveling in the blind. Final re-
    port to U.S. Office of Vocational
    Rehabilitation, Grant No. RD 510,
    1963.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
NAVAL SUBMARINE MEDICAL CENTER, Submarine Medical Research Laboratory	Unclassified
	2b. GROUP

3. REPORT TITLE

SENSORY BEHAVIOR OF NAVAL PERSONNEL: Monaural/Binaural Minimum Audible Angles of Auditory Response

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim Report

5. AUTHOR(S) (First name, middle initial, last name)

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SERGEANT, Russell L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
14 January 1970	17	41

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. MF12.524.004-9010D	SMRL Report Number 607
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Submarine Medical Center Box 600 Naval Submarine Base New London Groton, Connecticut 06340

13. ABSTRACT

This paper considers what one ear contributes to man's perception of his auditory world and evaluates the monaural/binaural role in spatial orientation. Minimum audible angles were determined for monaural listening to moving sounds, and results were compared to similarly obtained binaural data. Much usable directionality existed for the monaural mode even at poor azimuths, and for both modes of listening the accuracy of response depended upon type of acoustical signal used. These findings are related to a review of facts and theories of sound localization by man. Recommendations based on the results and conclusions of this study can be made to the Fleet to ensure the most efficient use of the auditory modality in a variety of Naval operations.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Auditory Localization						
Monaural Listening						
Spatial Orientation						
Minimum Audible Angle						

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